

What is claimed is:

1. A phase change memory device, comprising:  
a volume of memory material that includes:  
a plurality of discrete layers of phase change material, and  
5 a discrete layer of interface material disposed between each pair of  
adjacent phase change material layers, wherein the interface material is formed of  
a lattice mismatch material relative to the phase change material; and  
means for applying heat to the memory material volume;  
wherein a resistivity of the memory material is programmable to one of a plurality of  
10 generally distinct resistivity values in response to the heat applied to the memory material.
2. The phase change memory device of claim 1, wherein each of the phase  
change material layers includes a chalcogenide material.
- 15 3. The phase change memory device of claim 1, wherein the number of generally  
distinct resistivity values of the memory material volume exceeds by one the number of the  
phase change material layers in the memory material volume.
- 20 4. The phase change memory device of claim 1, wherein as the heat is applied  
over time to the memory material, the memory material exhibits periods of slower  
crystallization or amorphousization corresponding to the generally distinct resistivity values,  
and periods of faster crystallization or amorphousization corresponding to resistivities  
between the generally distinct resistivity values.
- 25 5. The phase change memory device of claim 1, wherein as the heat is applied to  
the memory material, the plurality of phase change material layers are crystallized or  
amorphousized generally in a sequential manner.

6. The phase change memory device of claim 1, wherein the means for applying the heat applies the heat as one or more thermal pulses.

7. The phase change memory device of claim 1, wherein the means for applying  
5 heat comprises a laser that directs a first laser beam onto the memory material volume.

8. The phase change memory device of claim 7, wherein the laser directs a second laser beam onto the memory material volume, and the phase change memory device further comprises:  
10 an optical sensor that measures a property of the second laser beam after the second laser beam reflects off of the memory material volume.

9. The phase change memory device of claim 1, wherein the means for applying heat comprises an electrode in electrical contact with the memory material volume, and  
15 wherein the electrode generates the heat as electrical current is passed therethrough.

10. The phase change memory device of claim 1, wherein the means for applying heat comprises a first electrode and a second electrode in electrical contact with the memory material volume, and wherein the heat is generated via electrical current passing through the  
20 first and second electrodes and the memory material volume.

11. The phase change memory device of claim 10, wherein the second electrode has a resistivity that is higher than that of the first electrode so that the second electrode generates the heat to create a temperature gradient across the memory material volume.  
25

12. The phase change memory device of claim 10, further comprising:  
a substrate;  
insulation material formed over the substrate and including a hole formed therein;  
spacer material disposed in the hole and having a surface that defines an opening  
5 having a width that narrows along a depth of the opening;  
the first electrode is disposed in the hole and has an upper surface;  
the volume of memory material is disposed in the opening and extends along the  
spacer material surface and at least a portion of the first electrode; and  
the second electrode is disposed in the opening and on the volume of memory  
10 material;  
wherein the second electrode and the volume of memory material form an electrical  
current path that narrows in width as the current path approaches the first electrode, so that  
electrical current passing through the current path generates the heat for heating the volume  
of memory material.
- 15
13. The phase change memory device of claim 12, wherein the current path  
reaches a minimum cross sectional area adjacent the first electrode upper surface.
14. The phase change memory device of claim 12, wherein the first electrode is  
20 disposed in the opening defined by the spacer material surface.
15. The phase change memory device of claim 12, wherein the spacer material is  
formed over the first electrode upper surface.
- 25
16. The phase change memory device of claim 15, wherein an indentation is  
formed into the first electrode upper surface, and a portion of the memory material volume  
extends into the indentation.

17. An phase change memory device, comprising:  
a plurality of memory cells formed on a substrate, wherein each of the memory cells includes:

5 a volume of memory material that includes a plurality of discrete layers of phase change material, with a discrete layer of interface material disposed between each pair of adjacent phase change material layers, wherein the interface material is formed of a lattice mismatch material relative to the phase change material;  
a first electrode in electrical contact with the memory material volume; and  
a second electrode in electrical contact with the memory material volume,  
10 wherein the volume of memory material is disposed between the first and second electrodes such that electrical current passing through the first and second electrodes and the memory material volume generates heat that is applied to memory material;  
wherein a resistivity of the memory material in each of the memory cells is programmable to one of a plurality of generally distinct resistivity values in response to the  
15 heat applied thereto.

18. The phase change memory device of claim 17, wherein each of the phase change material layers includes a chalcogenide material.

20 19. The phase change memory device of claim 17, wherein for each of the memory cells, the number of generally distinct resistivity values of the memory material volume exceeds by one the number of the phase change material layers in the memory material volume.

25 20. The phase change memory device of claim 17, wherein for each of the memory cells, as the heat is applied over time to the memory material, the memory material exhibits periods of slower crystallization or amorphousization corresponding to the generally

distinct resistivity values, and periods of faster crystallization or amorphousization corresponding to resistivities between the generally distinct resistivity values.

21. The phase change memory device of claim 17, wherein for each of the  
5 memory cells, the second electrode has a resistivity that is higher than that of the first electrode so that the second electrode generates the heat to create a temperature gradient across the memory material volume.

22. The phase change memory device of claim 21, wherein for each of the  
10 memory cells, as the heat is applied to the memory material, the plurality of phase change material layers are crystallized or amorphousized generally in a sequential manner.

23. The phase change memory device of claim 17, wherein each of the memory  
cells further comprises:  
15 insulation material formed over the substrate and including a hole formed therein;  
spacer material disposed in the hole and having a surface that defines an opening  
having a width that narrows along a depth of the opening;  
the first electrode is disposed in the hole and has an upper surface;  
the volume of memory material is disposed in the opening and extends along the  
20 spacer material surface and at least a portion of the first electrode; and  
the second electrode is disposed in the opening and on the volume of memory  
material;  
wherein the second electrode and the volume of memory material form an electrical  
current path that narrows in width as the current path approaches the first electrode, so that  
25 electrical current passing through the current path generates the heat for heating the volume  
of memory material.

24. The phase change memory device of claim 23, wherein for each of the memory cells, the current path reaches a minimum cross sectional area adjacent the first electrode upper surface.

5           25. The phase change memory device of claim 23, wherein for each of the memory cells, the first electrode is disposed in the opening defined by the spacer material surface.

10           26. The phase change memory device of claim 23, wherein for each of the memory cells, the spacer material is formed over the first electrode upper surface.

15           27. The phase change memory device of claim 26, wherein for each of the memory cells, an indentation is formed into the first electrode upper surface, and a portion of the memory material volume extends into the indentation.

20           28. A method of operating a phase change memory device having a volume of memory material that includes a plurality of discrete layers of phase change material and a discrete layer of interface material disposed between each pair of adjacent phase change material layers, wherein the interface material is formed of a lattice mismatch material relative to the phase change material, the method comprising:

            applying heat to the memory material volume to form a temperature gradient in the memory material volume for a predetermined amount of time, wherein a resistivity of the memory material is programmed to one of a plurality of generally distinct resistivity values in response to the heat applied to the memory material; and  
25           measuring the resistivity of the memory material.

29. The method of claim 28, wherein each of the phase change material layers includes a chalcogenide material.

30. The method of claim 28, wherein the number of generally distinct resistivity values of the memory material volume exceeds by one the number of the phase change material layers in the memory material volume.

5

31. The method of claim 28, wherein during the application of the heat, the memory material exhibits periods of slower crystallization or amorphousization corresponding to the generally distinct resistivity values, and periods of faster crystallization or amorphousization corresponding to resistivities between the generally distinct resistivity values.

10

32. The method of claim 28, wherein as the heat is applied to the memory material, the plurality of phase change material layers are crystallized or amorphousized generally in a sequential manner.

15

33. The method of claim 28, wherein the heat is applied as a plurality of separate thermal pulses.

34. The method of claim 33, wherein the measurement of resistivity includes measuring the resistivity of the memory material volume between the application of the separate thermal pulses.

20

35. The method of claim 28, wherein the heat is applied using a laser that directs a first laser beam onto the memory material volume.

25

36. The method of claim 35, further comprising:  
directing a second laser beam onto the memory material volume; and  
measuring a property of the second laser beam after the second laser beam reflects off  
of the memory material volume.

5

37. The method of claim 28, wherein the phase change memory device further  
comprises an electrode in electrical contact with the memory material volume, and wherein  
the application of the heat includes generating the heat by passing electrical current through  
the electrode.

10

38. The method of claim 28, wherein the phase change memory device further  
comprises a first electrode and a second electrode in electrical contact with the memory  
material volume, and wherein the application of the heat includes generating the heat by  
passing electrical current through the first and second electrodes and the memory material  
volume.

15

39. The method of claim 38, wherein the second electrode has a resistivity that is  
higher than that of the first electrode so that the second electrode generates the heat to create  
a temperature gradient across the memory material volume.

20

40. The method of claim 38, wherein the electrical current is passed from the  
second electrode to the first electrode, and from the first electrode to the second electrode.

25